



***Night-time 36-band MODIS data for
Mapping global urban population, GDP and
CO₂ emissions***

***Jan-Peter Muller, Chris Doll
University College London***

***Chris Elvidge
NOAA/NGDC***



DEPARTMENT OF GEOMATIC ENGINEERING

Overview

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Scientific Justification

- **Urbanisation is one of the principal driving forces of global change. In 1945, 30% of global population lived in urban areas. By 1995, 45% and by 2025 extrapolated to be 60%**
- **Urban land cover class difficult to detect from daytime visible/NIR imagery due to non-linear mixtures of vegetation and buildings.**
- **Census data not collected in an uniform manner worldwide and only refers to residential areas not industrial areas where greenhouse gas emission may be much greater**
- **Night-time lights has been hypothesized to reflect socio-economic status and Carbon Dioxide emissions**
- **MODIS night product could be used initially to supplement land cover but eventually could be a rich source of socio-economic information which cannot be collected in any other way**



Objectives

- **assess potential of night-light images to derive global information**
 - **urban land cover**
 - **socio-economic statistics (primarily population and GDP)**
 - **CO₂ emission**
- **use ancillary information on city populations to derive relationship with lit area**
 - **By continent**
 - **By country**
- **Assess potential of MODIS to provide annual estimates of CO₂ emission and global urban population**
 - **using simulated radiance images from AVIRIS**
 - **Using MCST/SBRC calibration information from MODIS**



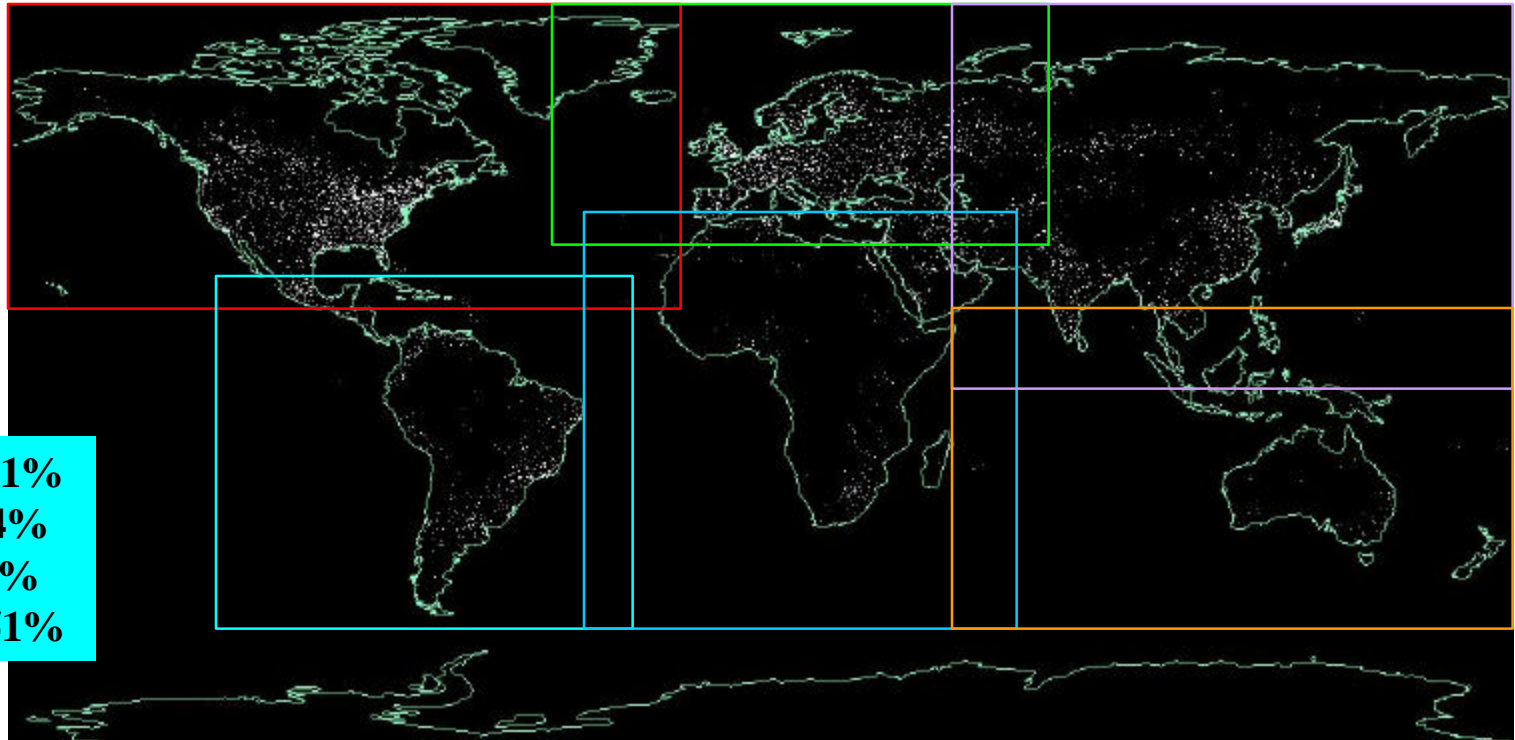
DMSP-OLS 1km global composite

- **1km maps of 1994-95 DMSP-OLS visible/NIR data acquired at night produced by C. Elvidge at NOAA-NGDC**
- **Digital DMSP-OLS data was cloud-screened using thermal IR channel and remapped to Plate Carée and Interrupted Goode Homosoline**
- **Maps produced in two different outputs:**
 - **Frequency of occurrence over the compositing time period as a percentage of the whole time period**
 - **Mean brightness over the time period when observation was cloud-free**
- **Global maps were then edited to exclude biomass burning, gas flare burn-offs and non-land data to create “city lights”**
- **Occurrence frequency employed in this analysis as mean value was less reliable**
- **Resultant map polygonised using a threshold of 7% (Elvidge et al., 1997)**



City "lights at night" (DMSP-OLS) : Global lit area map showing continental region boundaries

North American Coverage, **South American Coverage,** **Asian Coverage,**
European Coverage, **African Coverage,** **Oceania Coverage**



OLS Lit area=3.81%
IGBP urban=0.54%
UMd urban=0.51%
WHS urban=0.051%



Ancillary data-sets used for analysis

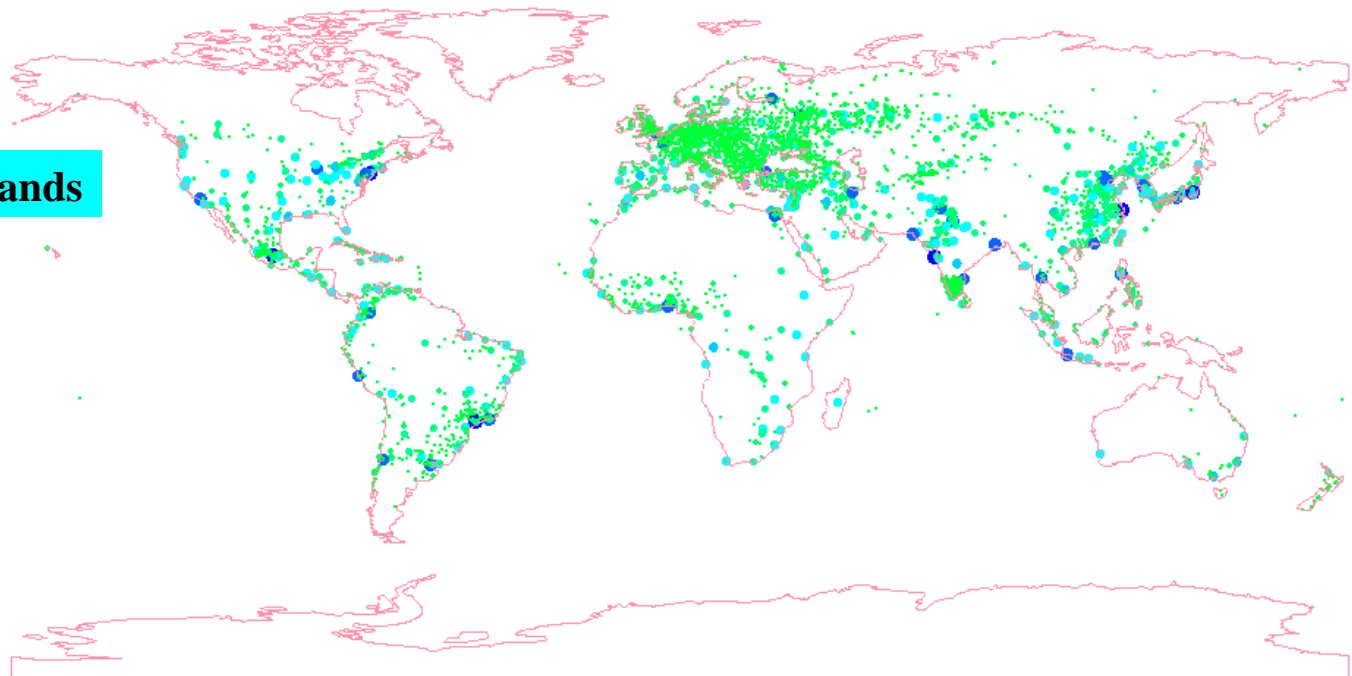
- **University of Iowa Center for Global & Regional Environmental Research (CGRER) of 49,935 urban centers worldwide (mostly pre-1993) of latitude, longitude and population**
- **Philip's Geographical Digest (1998) on 2,453 urban agglomerations of capital cities and those with >100,000 used to replace CGRER data (mostly 1994-95)**
- **World Resources Institute (WRI) country-level data on**
 - **Population (1995)**
 - **Urban Population (1995)**
 - **Number of cities > 750,000 inhabitants (1995)**
 - **Gross Domestic Product Purchasing Power Parity - GDP-PPP (1993)**
 - **CO₂ emissions-Total, Liquid[oil], solids [coal], gas, cement (1992)**



Map showing global city population data from CGRER and Philip's Geographical Digest

Population in thousands

- 25 - 122
- 122 - 298
- 298 - 579
- 579 - 1046
- 1046 - 1796
- 1796 - 2898
- 2898 - 4466
- 4466 - 8089
- 8089 - 12410
- 12410 - 26836



Population Information from remote sensing

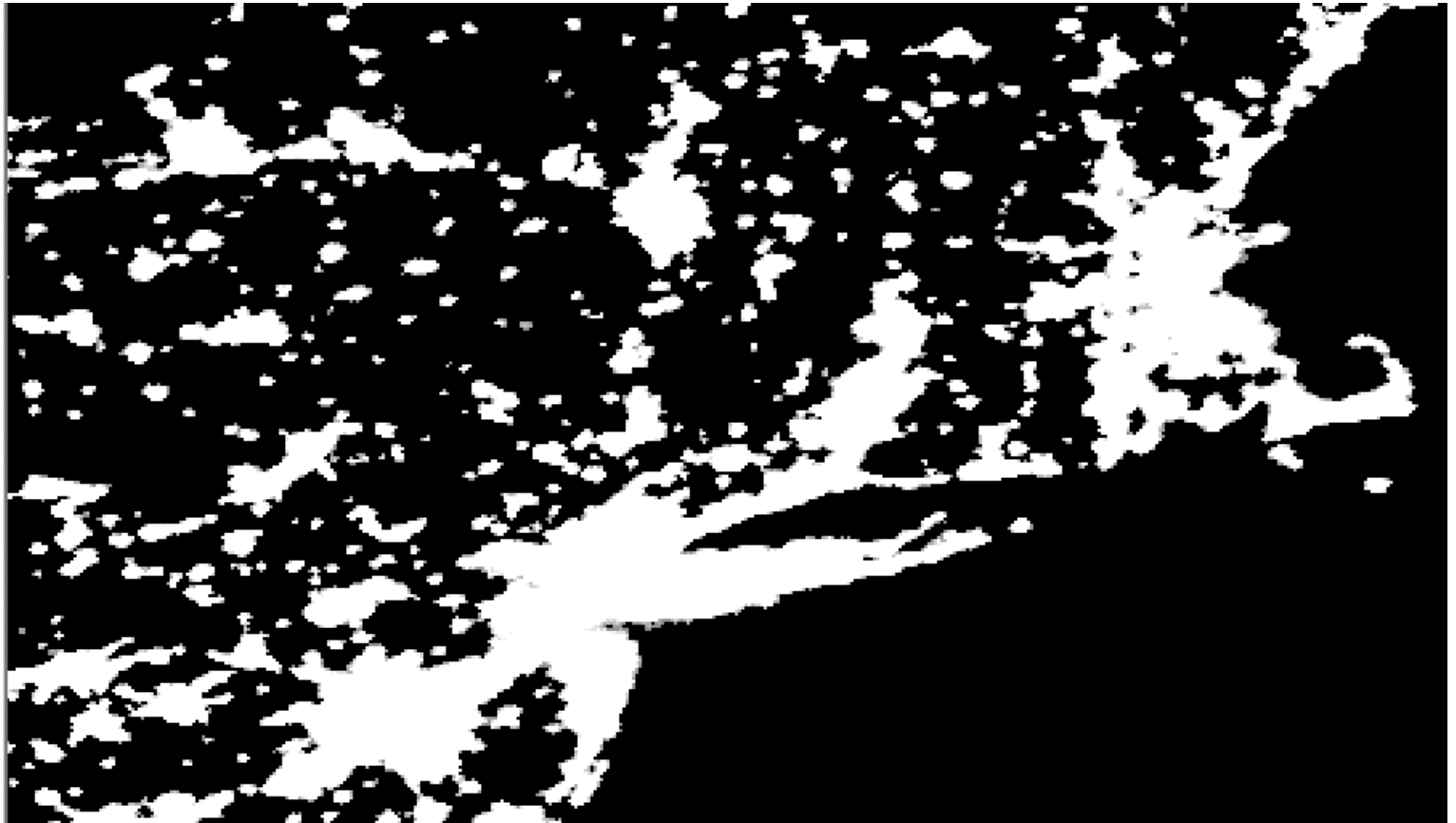
- **Nordbeck (1965) identified allometric relationship between area, A and population, P, of settlements based on cartographic data**

$$\mathbf{A = aP^b \quad \Rightarrow \quad \text{Log A} = b(\text{LogP}) + \text{Log a}}$$

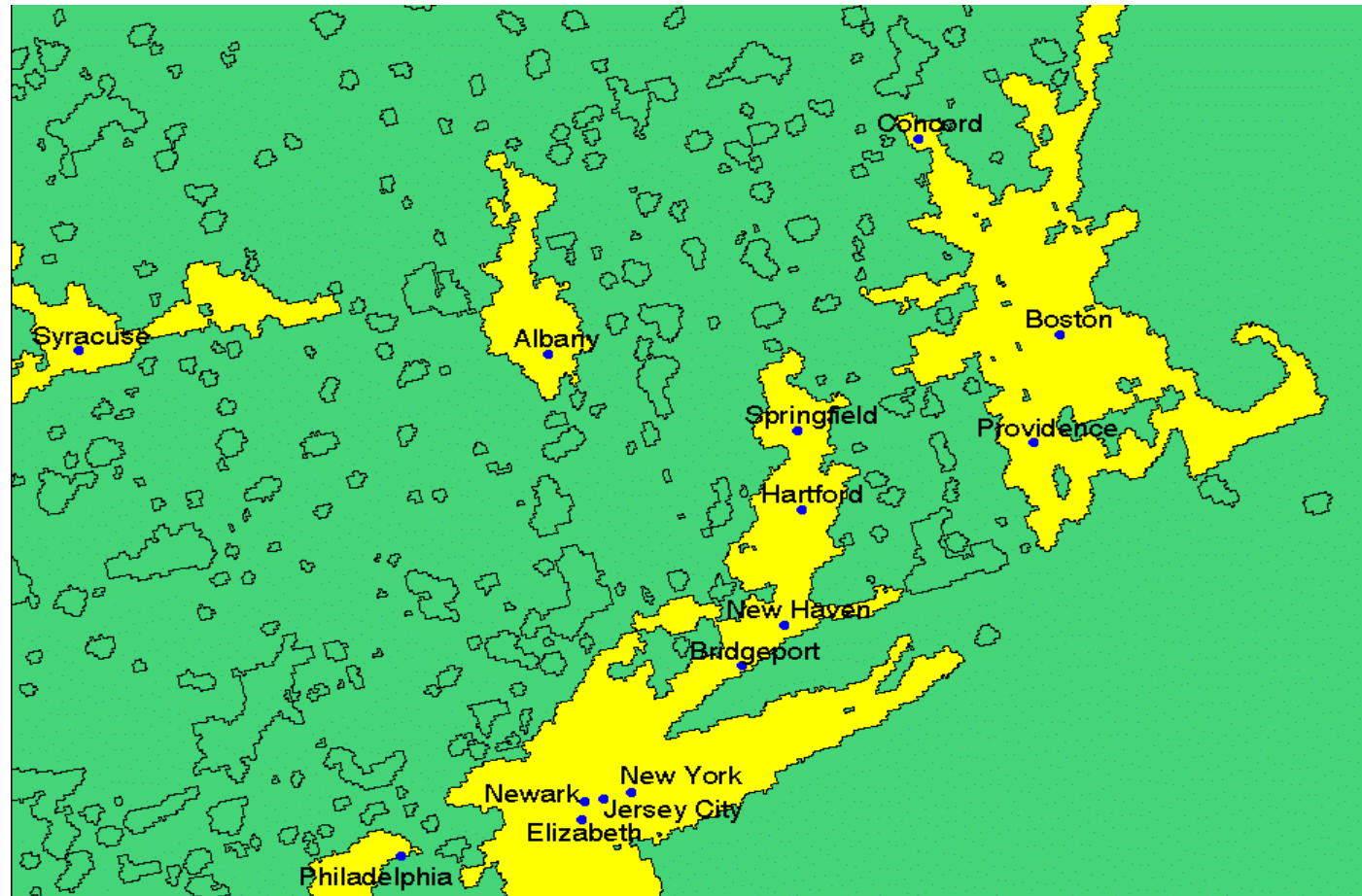
- **Tobler (1969) provided satellite confirmation with photographs from the Gemini missions**
- **Welch (1985) & Lo (1986) showed use of DMSP-OLS photographic products for urban area mapping**
- **Renewed interest in DMSP-OLS data since digital archival in 1994. Digital processing facilitates more accurate areal assessment**



Example of DMSP-OLS 1km 1994-5 composite frequency image of New York area



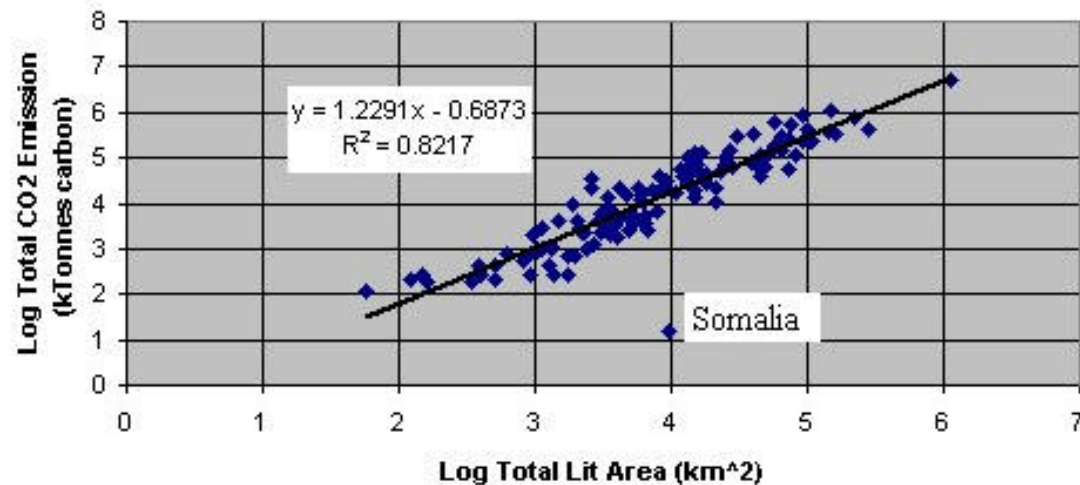
Example of polygonised areas with cities > 100,000 population shown as points within polygon. Note that a lit area may contain multiple points



Relationship of lit area from "lights at night" (DMSP-OLS) with Total CO₂ emissions

Note: strong allometric relationship of Total CO₂ emissions to lit area.

Total CO₂ Emission vs. lit area (by country)

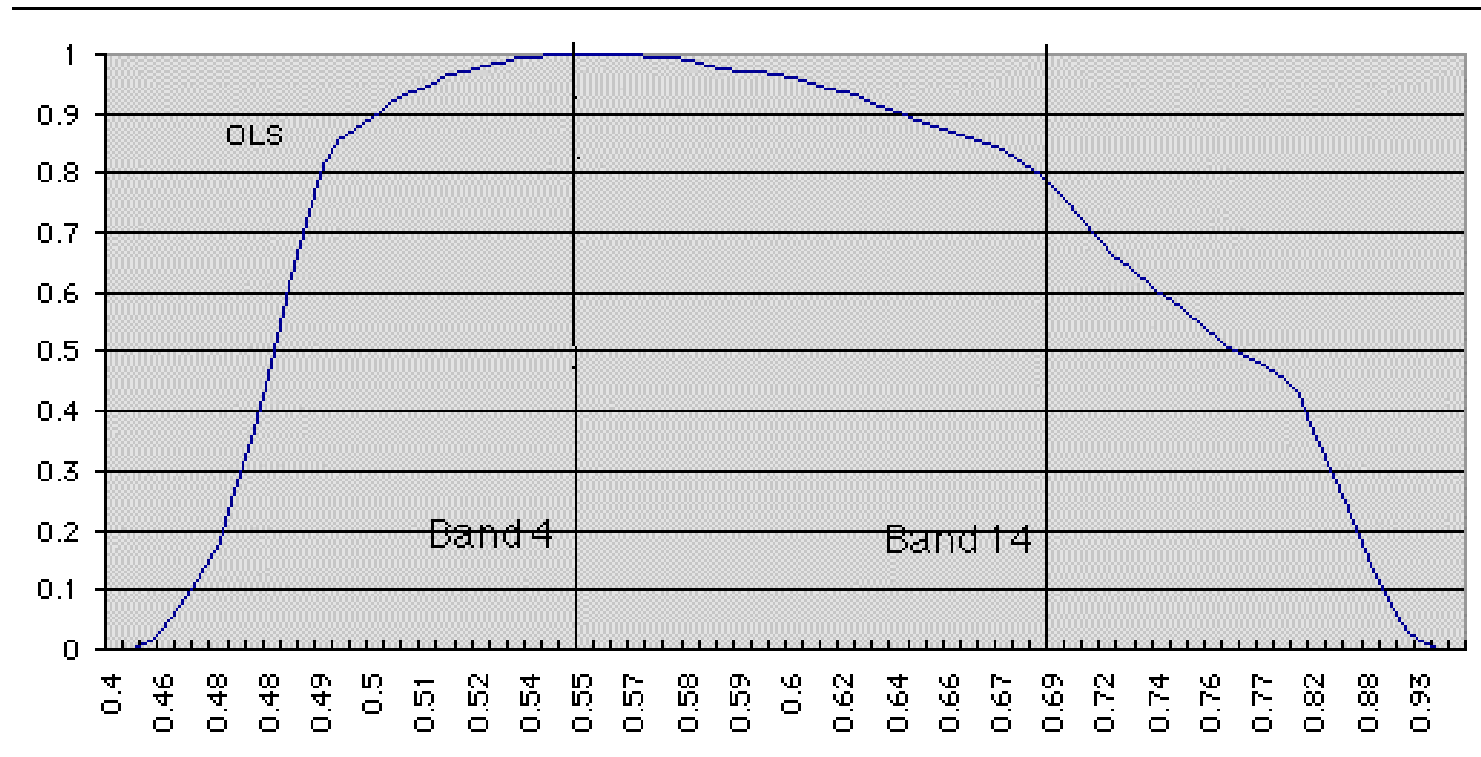


Assessing the potential of MODIS from night-time lights using AVIRIS

- **AVIRIS data collected over Las Vegas, NV using low-altitude flight with IFOV=5m (C. Elvidge, PI) in 1997**
- **AVIRIS data converted to radiance using supplied calibration data**
- **Integration over MODIS, MISR & OLS spectral band responsivities at 5m**
- **Integration over 250m given limited swath width of AVIRIS**



Comparison of OLS spectral responsivity with most sensitive MODIS Bands (4 & 14)



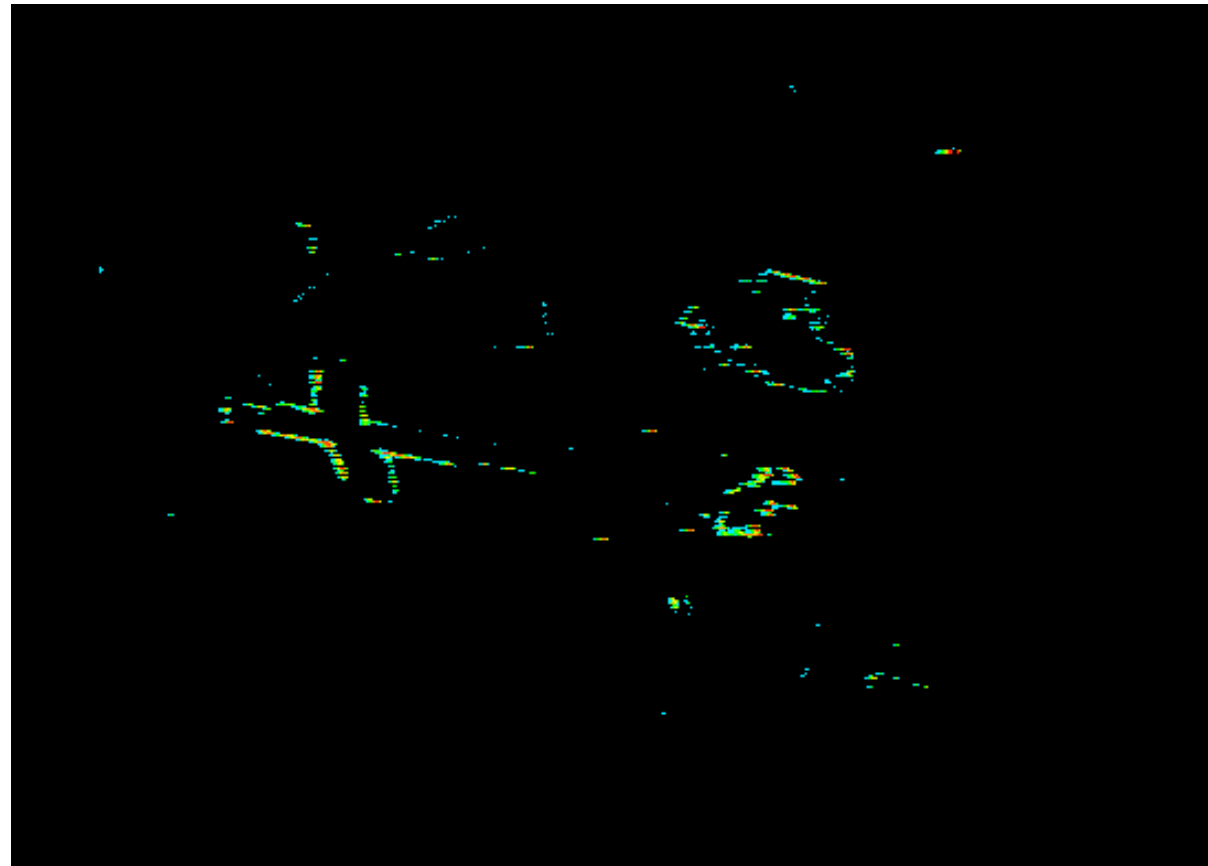
Example of AVIRIS at 5m integrated over 15 MODIS bands (1-4, 8-19)



1×10^{-10}

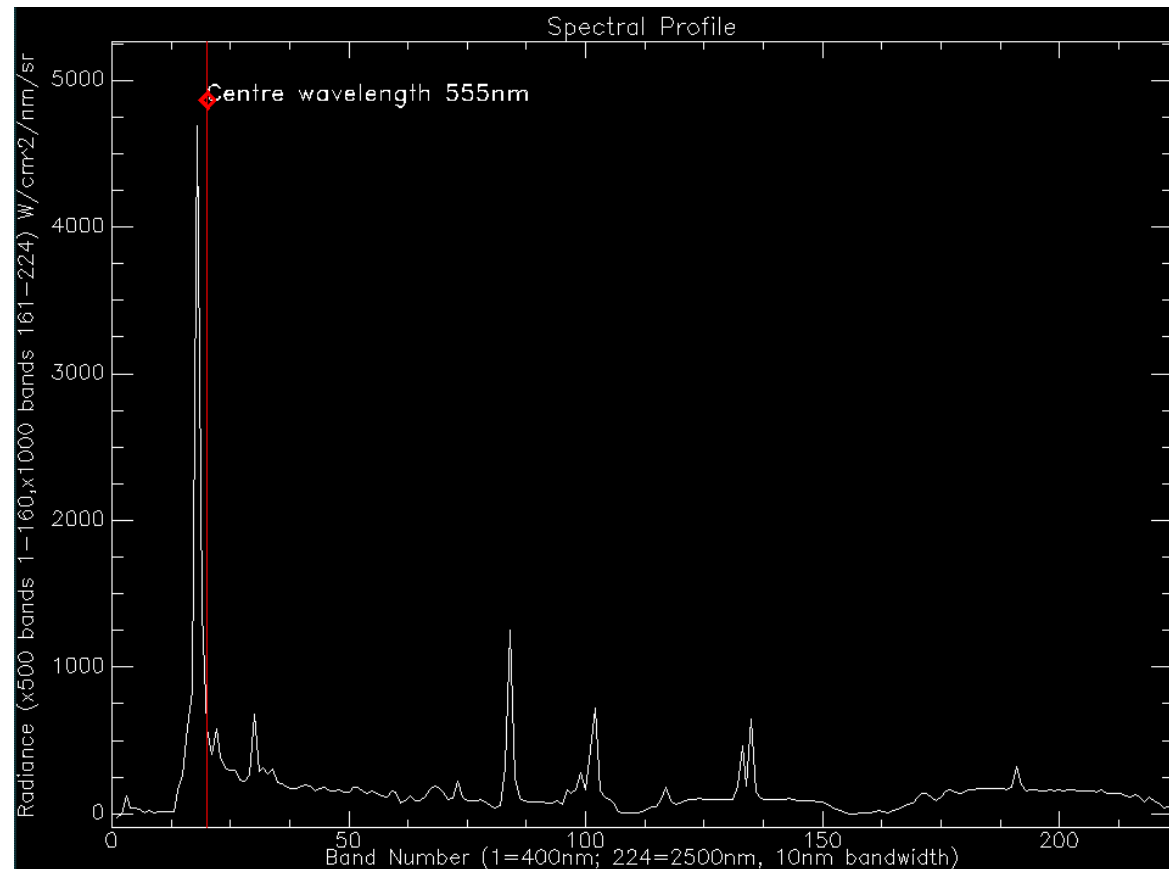
4×10^{-7}

$\text{W/cm}^2/\mu\text{m/sr}$



Example of AVIRIS spectral profile and Band 4 location

Emission peak
for lights at 536
nm of radiance
 10^{-8}
 $\text{W/cm}^2/\mu\text{m/sr}$



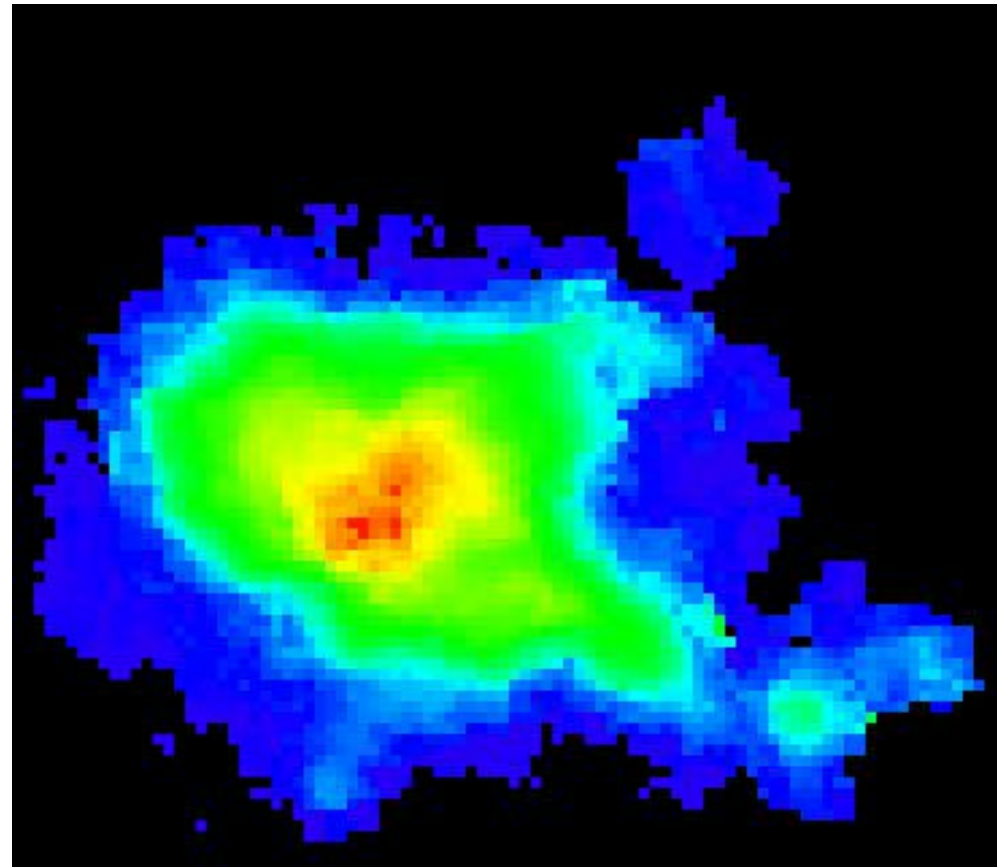
Comparison with OLS 2.7km radiance image for 1994/5



4×10^{-7}

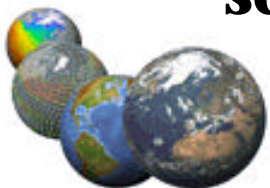
4×10^{-7}

$\text{W/cm}^2/\mu\text{m/sr}$



Quantitative assessment of MODIS minimum detectable radiance

- **Minimum detectable radiance defined as Maximum radiance/dynamic range (=4096 for MODIS) taken from MCST spreadsheet (June 1997)**
- **OLS minimum radiance (Elvidge et al., RSE (in press) is around 5.412×10^{-7} W/cm-sr- μ m**
- **MODIS bands 1-4, 8-14 integrated in radiance and spatially integrated up to 250m (would be 16 times smaller for 1km pixels) would yield minimum detectable radiances of 3.163×10^{-7} W/cm-sr- μ m**
- **Appears that MODIS will be (just) able to detect night-time lights at higher spatial resolution, with better radiometric calibration and better cloud screening than OLS**



Post-launch product from MODIS - Next Steps

- **Propose a new “post-launch” product for URBAN AREA, GDP and CO₂ emission studies derived from MODIS based on**
 - **1km thermal day-night contrast (of direct interest to studies of the net radiation budget changes caused by cities)**
 - **Bands 1-4, 8-14 (250m-1000m) night-time visible “city lights” would be converted to radiance and summed to produce**
 - » **Maps of lower population densities**
 - » **Studies of land use conversion into urban areas with much greater reliability than using existing mixed pixel land cover**
- **Resultant product could also be used to help interpret MOPITT & HRDLS CO measurements**
- **Request that MODIS project tests concept during the commissioning phase of the mission and if results are encouraging to invest in additional data acquisition (Bands 1-4, 8-14 globally at night)**

